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PARAMETERS AFFECTING GENETIC ALGORITHM IN LEAK DETECTION BY INVERSE TRANSIENTS ANALYSIS

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Abstract: *Leak detection is very important in Pipeline. When occurs a Leak in pipeline, there is an associated loss of product and increased pumping. Additional there are environmental impacts. Leaks occur in pipes due to various reasons such as poor quality of pipe materials and workmanships, faults in operation and maintenance, corrosion, internal and external high pressures. Leaks as usual events in pipes, create difficulties for operation management and also impose significant costs from economic and environmental point of view. Therefore academic and practical development of leak detection methods are highly demanded in water networks industry. A new methods of Leak detection is Inverse Transients Analysis (ITA) .Transient state can be initiated in the pipes by closing the downstream end valve. The time history of pressure fluctuations is measured at the valve location as downstream boundary condition. The time duration of valve closure is determined long enough to minimize water hammer effects. In this paper used Pressure head measurements made during a transient event. Using characteristics method and inverse mathematics the pipe parameters – Leak areas, friction coefficients - were adjusted to match observed pressure in the numerical model. The solution parameter set was determined by minimizing an objective function that represents the match between the numerically modeled heads and measured heads. The objective function is derived by defining the least- squares criterion. The Leak areas at characteristic nodes are considered as decision variables .Leak parameters are determined using Genetic algorithm method. Parameters of Genetic Algorithm are Crossover , mutation, initial population ,etc. The various crossover techniques are discussed as single point crossover, two point crossover and uniform crossover. After crossover, the strings are subjected to mutation. The various mutation techniques are discussed as fixed mutation and Linear mutation. This paper investigates kinds of parameters of Genetic Algorithm that may affect convergence and time of arriving best solution in Inverse Transients Analysis. The paper concludes with a number of case studies showing how these parameters affect best solution in Genetic Algorithm in a simple reservoir – pipeline-valve system.*

Keywords: *Leak detection, Genetic Algorithm, Transient Inverse Analysis, Crossover , mutation*

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INTRODUCTION

Leakage control and demand management have become high priorities for water supply utilities and authorities. This is not only because there is a greater understanding of the economic and social costs associated with water losses, but there is also an imperative to make best possible use of the natural resource that is water (Covas, et al. 2003). Over the past century, there have been many different methods to detect underground pipeline leaks in water distribution systems. The ideal technology for assessing distribution system integrity should be non-intrusive, should not interrupt operations and should be adaptable to the complex array of materials and conditions present (Tafuri, 2000).

Various mathematical and hydraulic models have been proposed to estimate the magnitude of leakage rates and locate leaks in pipelines and pipe networks. Pudar and Ligget (1992) were able to detect and locate leaks in pipe networks using an inverse problem approach. The method requires pressure and/or flow measurements at various nodal points in the pipe network. The number of measurements are varied to formulate three problems–over-determined, even determined, and underdetermined. Leaks at nodes are considered to be the unknowns and are expressed in terms of pressure by an orifice formula. However, the method can be applied only under steady state conditions, requires accurate pipe friction factors, and huge amount of pressure and flow measurements. The inverse transient approach adopted by Ligget and Chen (1994) uses transient flow conditions to calibrate and detect leaks in pipe networks. As in the previous work, leaks are defined by an orifice equation. The method is computationally intensive and convergence of solution is not certain.

Vitkovsky, Simpson, and Lambert (1999) developed a unique method to estimate magnitude of leaks using transients and genetic algorithms. Under unsteady conditions of flow, numerically modeled hydraulic grade lines are fitted against measured HGLs. The negative sum of absolute differences between measured and modeled pressure heads are then maximized to solve for Darcy-Weisbach pipe friction factors (f) and lumped leak coefficients. Leakage is simulated using an orifice equation. An average error of 3.43% for the estimated friction factor and 0.5% for the leak parameter is found from the test simulations. However, the method is applied only to a test network consisting of 11 pipes and 7 nodes. The applicability of the method to large pipe networks and pipeline is not discussed.

Mpesha, Gassman, and Chaudhry (2001) applied the frequency response method to detect and locate leaks in pipelines. The method requires pressure measurements at the valve. A frequency response diagram is created at the valve by periodic opening and closing of the valve. The steady–oscillatory flow thus created at the valve is analyzed in the frequency domain using the transfer matrix method. Resonant pressure amplitude peaks in the frequency response diagrams are compared in the presence and absence of leaks to detect leaks. Extensive measurements of hydraulic parameters are not required in this method and leaks up to 0.5% of the mean discharge can be detected for various values of friction factors. The authors use a similar method to detect leaks in transient flow conditions (Mpesha, Gassman, and Chaudhry, 2002). Transients created by opening and closing of a valve are analyzed using the method of characteristics. The method detects and locates leaks in pipelines with friction factors ranging from 0.01 to 0.025.

Wang et al. (2002) introduced an academic approach to detect a leak in a pipe based on the contribution of the leak in transient damping in company with steady friction losses, using Fourier series for solution of linearized transient differential equations. The results showed that the Fourier components are damped uniformly by steady friction factor whereas the leak damped each component differently. Covas et al (2005) proposed a new approach by means of the standing wave difference method (SWDM). This method is based on analysis of the frequency response of the system in steady- oscillatory flow state, employing steady friction loss modeling. Kim (2005) integrated the genetic algorithm into the impulse response method and developed a leak detection technique, using the inverse frequency analysis. Unsteady friction loss modeling was used in this technique. Lee et al. (2005) proposed two methods based on frequency domain analysis, involving the inverse response method and the peak-sequencing procedure. Unsteady friction losses also are considered in their method. Lee et al. (2007) also developed an experimental modeling to show the validation of the above method for leak detection in pipes. They also presented some arguments about abilities and limitations of the mentioned method. Nixon and Ghidaoui (2007) published an interesting paper to show the importance of unsteady friction effects on transient analysis for pipes with external fluxes such as leaks. They also investigated the damping rate of the leak detection method presented by Wang et al. (2002) as a case study. Almost in all presented methods, transient state is initiated by the valve closure, considering a specified closure pattern for new valves. Numerical modelling of the valve operation especially for oscillatory types in real life pipes would face serious concerns (Mpesha et al 2001; Lee et al 2005; Covas et al 2005; Kim 2005).It is introduced a new method of leak detection in pipelines based on inverse transient analysis in time domain by Shamloo and haghighi (2008) . The numerical modeling of transient analysis in the pipe is developed using the method of characteristics (MOC) backwardly. An inverse problem is applied for leak detection by defining the least-squares criterion objective function. The leak areas at characteristic nodes are considered as decision variables. Leak parameters are determined using the sequential quadratic programming (SQP) method. SQP Method needs beginning point for optimitization . This optimization method is computationally intensive with first point and convergence of solution is not certain.

The approach adopted by (Shamloo and Haghighi, 2008) and followed in this study made use of the Extended Inverse transient analysis and genetic algorithm to estimate leakage at specified locations along the line. In this approach the method of inverse analysis has been applied using the method of characteristics (MOC) and Genetic Algorithm(GA). The transient flow is produced by closing the valve with a determined closure time to reduce the effects of unsteadiness and uncertainties of friction factor and also water hammer parameters. Sampled pressure fluctuations at the valve location are used as the downstream boundary conditions for the numerical model of the pipe. In the following section, the governing equations for transient flow with a leak are derived and genetic algorithm parameters describing the behavior of convergence of solution are discussed. The leak detection method is developed in the next section followed by a numerical example. Finally, results of experimental tests are presented.

Governing equations

The continuity and momentum equations governing the transient flow in pipelines for most engineering applications can be written as following (Chaudhry 1987):

$$\frac{\partial H}{\partial t}+\frac{a^2}{gA}\frac{\partial Q}{\partial x}=0 \tag{1}$$

$$\frac{\partial H}{\partial x}+\frac{1}{gA}\frac{\partial Q}{\partial t}+\frac{fQ|Q|}{2DA}=0 \tag{2}$$

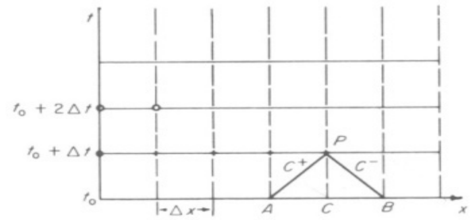

Fig. 1. Characteristics grid

Where X=distance along the pipe; t=time; a=wave speed; g=gravitational acceleration; A=cross sectional area of the pipe; D=diameter of the pipe; Q=instantaneous discharge; H=instantaneous piezometric head; and f=Darcy-Weisbach friction factor which is considered to be steady (or quasi- steady) in the present work. These equations are solved by the method of characteristics (MOC), considering the initial and boundary conditions of the pipe. Two above equations are combined linearly and resulting equations are integrated then following explicit equations are obtained (Chaudhry 1987):

$$(H_p-H_A)+\frac{a}{gA}(Q_P-Q_A)+\frac{f\Delta t}{2gDA^2}Q_A|Q_A|=0 \tag{3}$$

$$(H_p-H_B)-\frac{a}{gA}(Q_P-Q_B)-\frac{f\Delta t}{2gDA^2}Q_B|Q_B|=0 \tag{4}$$

where Q_A, Q_B and Q_P are instantaneous discharges, H_A, H_B and H_P are instantaneous piezometric heads at points A, B and P, respectively (Fig. 1). Equation 3 is valid along the positive characteristic AP (C^+) and Eq. 4 is valid along the negative characteristic BP (C^-) in each partial space of Δx and time step of Δt.

Friction loss modeling

The purpose of transient modelling herein is to develop a leak detection method for real-life pipes. Friction loss is taken into account as a serious uncertainty in ITA which may be considered to be a steady, quasi steady or unsteady phenomenon. In case of unsteady-flow, where energy losses due to viscous effects are very important, approximation of the friction loss by quasi-steady approach in compatibility equations may cause some concerns. Examples may include long oil pipeline, very high flow velocities, or highly viscous flows in small-diameter pipes (Wylie and Streeter 1993). Traditionally the steady or quasi-steady friction terms are incorporated into the standard water hammer algorithms. This assumption is satisfactory for slow transients where the wall shear stress has a quasi-steady behaviour (Bergant et al. 2001). But in case of leak detection it is needed that the numerical modeling be as accurate as possible. So in this work, friction factor is considered unsteady using the formulation recommended by Brunone et al. (1991a), (1995) with improvements introduced by Vitkovsky et al. (2000a) as following:

$$f = f_q + \frac{kD}{V|V|}\left(\frac{\partial V}{\partial t} + a\,sign(V)\left|\frac{\partial V}{\partial x}\right|\right) \tag{5}$$

where *fq* is Darcy-Weisbach friction factor from Colebrook formula, sign(Q) ={+1 for $Q \geq 0$ and -1 for $Q<0$} and *k* is the Brunone friction coefficient which can be estimated either empirically or analytically. Using Vardy and Brown's shear decay coefficient C^*, *k* can be estimated analytically as following (Vardy and Brown. 1996):

$$k = \frac{\sqrt{C^*}}{2} \tag{6}$$

where $C^* = 0.00476$ for laminar flow and $C^* = 7.41/\mathrm{Re}^{\log(14.3/\mathrm{Re}^{0.05})}$ for turbulent flow. Using a simple explicit finite difference scheme, Equation 5 is posed in Equations 3 and 4 to model unsteady friction loss behaviour.

Leak simulation

In order to verify the possibility of locating a possible leak on the basis of the results of transient tests, the effects of a leak on wave propagation from the numerical point of view are introduced. When numerically modeling unsteady-state flow in pressurized pipes (Wylie and Streeter 1993), the instantaneous value at time *t* of the discharge through a leak, can be visualized by orifice formula.

Leak effects in a pipe are function of orifice shape, transient characteristics, leak location and groundwater level for underground pipes, particularly in coastal cites. The leak discharge is expressed by the orifice equation:

$$Q_L = A_e\sqrt{2g(H_L - Z_L)} \tag{7}$$

Where $A_e = C_d A_L$ = effective leak area; Q_L = leak discharge; C_d = Coefficient of discharge; A_L = apparent leak area; Z_L and H_L are the elevation and the instantaneous piezometric head at the leak location respectively. Equation (5) in company with the defined positive and negative characteristic equations is developed at leaky nodes.

TRANSIENT GENERATION

In order to detect leak, transient state is generated by closure of the valve in the pipe. Speed of closure controls the intensity of transient fluctuations and plays an effective role in the ITA based method's performance. This is an accepted fact that sharper transients contain more information about the pipe and flow features and therefore are more useful to apply in leak detection. But from practical point of view there will be some concerns using sharp transients such as: higher uncertainties and unsteadiness effects of friction loss modeling in sharp transients, viscoelastic behaviors of the pipe-wall material, blockage effects, fluid-structure interaction which are more sensitive in sharp transients, undesirable positive and negative waterhammer pressures may damage the pipes, cavitations and water column separation along the pipe. Therefore, in the present work the speed of valve closure and consequently transient intensity is considered slow enough to prevent waterhammer pressure and above mentioned concerns. Pressure fluctuations at the valve location, as the measurement site, are sampled as a signal until the generated transient decays.

Unknown leaks' parameters in the pipe including the number, location and size of leaks, lead us to assume that all of the characteristic nodes are leaky except those of the reservoir and the valve. In this condition, leak effects are considered at all nodes with unknown leak area. Actually by this assumption, three kinds of unknown leaks' parameters (the number, location and size) are limited to only leaks' size at characteristics nodes. Detection of the leaks with non-zero area results in detection of the other leaks' parameters. So the leak detection procedure is proposed as following:

a) Transient flow is generated in the pipe by gradually valve closing. The valve closure time is considered long enough to minimize the effects of unsteadiness and uncertainties of friction factor and also waterhammer.
b) At the next step, the described backward transient model is developed in the pipe as a function of leaks' area at characteristic nodes.
c) An inverse procedure is applied for leak detection, introducing nonlinear programming (*NLP*). Leaks' area at nodes are considered as decision variables and a least-squares criterion objective function is defined as follows:

$$C = \sqrt{\sum_{i=1}^{n} (H_{Vi} - H'_{Vi})^2} \quad (8)$$

Where C=objective function value; n=number of calculated valve heads; Hvi ′ and Hv = calculated and observed valve head. To detect the leaks' parameters in the pipe, the objective function(6) must be minimized subject to the following constraint:

$$0 \le A_{ej} \le A_{eMax} \quad (9)$$

In which (A_{ej}) =effective leak area at node j; $(A_e)_{max}$ = maximum limit of the leak area and is determined as a reasonable ratio of the pipe cross sectional area.

In the present work the objective function is minimized by the method of genetic algorithm (GA) using numerical model, which is known as a powerful nonlinear optimization method.

d) At the end of minimization, if the leak's area of a node is found to be non-zero then it will be introduced as a leaky node. Ultimately the number, location and size of leaky nodes determine the leaks' parameters in the pipe.

Gentice Algorithm

To solve the introduced *NLP*, an optimization algorithm is developed and applied here based on genetic evolutionary algorithms. GA family is the most well-known natural optimization methods and is applied widely in many complex engineering problems. In this work a binary GA is used. The GA begins by defining the problem's chromosome or an array of parameters to be optimized (Haupt, 1998). In the leak detection problem the genetic chromosome consists of an array with *n* members. For each type of parameters (leak location and area) a number of binary genes(bits) are considered with respect to each parameter entity. For real values of leak areas (*Ae*) suitable number of *N*is considered based on desirable accuracy.

After initial definitions a large commune of binary chromosomes known as initial population is generated by GA. Then each chromosome in the population is decoded to real values with respect to the arrangement of decision variables. And the leak areas are decoded as real values using as follows (Haupt, 1998):

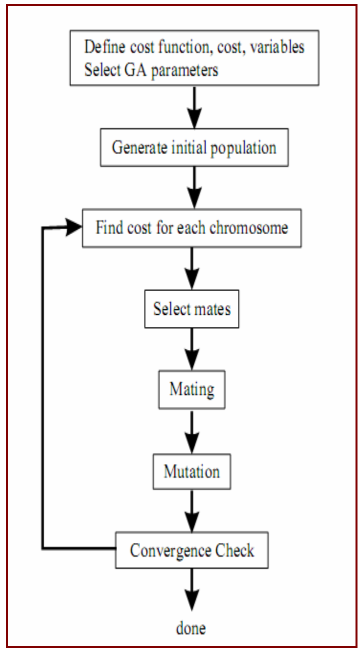

Fig. 2. Flowchart of a binary GA.

simple genetic algorithm are carried out including mate selection and paring to reproduce a new generation, mutation and convergence testing. In all reproduced new generations chromosomes are decoded using Equation 7. For more information, the method of weighted random paring is considered as the policy of parent selection (Haupt, 1998). Figure 2 illustrates the method application steps and the inner GA solver.

Selecting GA parameters like mutation rate, μ, and population size, *Npop*, is very difficult due to the many possible variations in the algorithm and cost function. A GA relies on random number generators for creating the population, mating, and mutation. A different random number seed produces different results. In addition there are various types of crossovers and mutations, as well as other possibilities, like chromosome aging and Gray codes. Comparing all the different options and averaging the results to reduce random variations for a wide range of cost functions is a daunting task. Plus the results may be highly dependent on the cost function analyzed.so in this paper is investigated affecting parameters of GA in leak detection by inverse transient analysis. At first in this paper is compared population size by random number of 0 and 1 in simple reservoir –line – valve with one leak.then using results of first step is investigated crossover operators in one point,two point and uniform. At third step is compared mutation in linear and fix ratio. the standard deviation of objective function values of sequence generations is considered as the GA's convergence criterion which is aimed to be less than a very small quantity of ε judged for each problem.

Results

To demonstrate abilities of genetic algorithm a Reservoir-Pipe-Valve (RPV) system with hypothetical leaks are defined to detect the leak parameters inversely. This example presents a single pipe system including only one leak with L=1000m ; D =350 mm; e=0.05;F=0.03 ; a= 1000 m/s and Hr =20m . The leak distance from the upstream reservoir x=400m and the leak area A_{el}=2.5 cm^2 equals to %0.25 of the pipe cross sectional area. After initiating the transient state in the pipe, pressure fluctuations at the valve location are sampled after the valve closure with sampling frequency fr_s=10Hz (Figure 4).

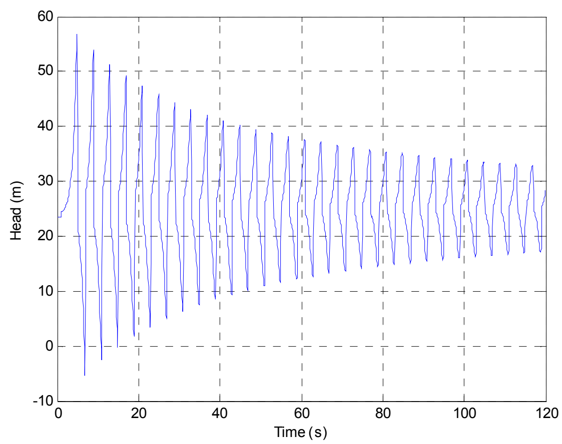

Fig.3. Sampled pressure fluctuations after valve closure in example 1

Produced signals (Figure 3) are used as downstream boundary condition in the backward analysis model. Regarding the sampling frequency and the wave speed, a characteristic grid can be developed with st 1.0=Δ and mx 100=Δ . Therefore the problem is comprised of 9 decision variables which are assumed leak areas at nodes. The constraint of each decision variable is considered to be as an engineering judgment. The trend of objective function minimization can be seen in figure (4) using the GA method in determination of the leaky nodes.

First population

In GA is considered the first population size as variable and other parameters like generation population size, chromosome length , crossover and mutation as constant . In this paper is used Npop=20; CL=5 bits;one point crossover and fix mutation ratio=0.5 for every first population size.

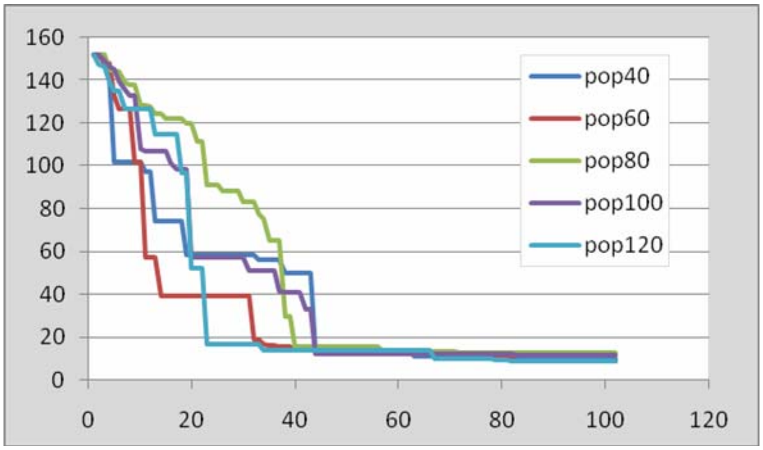

Fig.4. Trend of minimization of the objective function in example 1

Optimized decision variables which introduce leaks' parameters in the pipe have been illustrated in Table (1).

Table 1. Optimized decision variables of example1

ITA by GA	Area of decision variables(cm^2)									Error of area	Objective function
	1	2	3	4	5	6	7	8	9		
decision variables	0.00	0.00	0.00	2.40	0.00	0.00	0.00	0.00	0.00	-------	0
First population size 40	0.00	0.01	0.00	1.90	0.52	0.00	0.00	0.00	0.00	20.83%	1.25
First population size 60	0.00	0.87	0.00	2.20	0.00	0.00	0.90	0.00	0.00	8.33%	0.923
First population size 80	0.00	0.00	0.00	2.30	0.00	0.00	0.00	0.00	0.00	4.17%	0.767
First population size 100	0.00	0.00	0.00	2.35	0.00	0.00	0.00	0.00	0.00	2.08%	0.679
First population size 120	0.00	0.00	0.00	2.36	0.00	0.00	0.00	0.00	0.00	1.67%	0.564

According to this Table, it can be concluded that the first population have a gene pool larger , GA is found good solution faster because the algorithm will explore a big part of the search space and can find global optimal solutions, but it has considered that the time required by GA to converge is important. Comparing resultsof population size of 100 and 120 with the precise location and cross sectional area of the leak, 2.08% and 1.67% error are observed respectively. These estimates are acceptable regarding to the low sampling frequency(frs=10 Hz) in this example. It is obvious that by using higher sampling frequency, the results will be more accurate. Practically, a population size of around 100 is quite suitable , but anyway this size can be changed according to the time and the memory disposed on the machine compared to the quality of result to be reached.

Crossover

In second step is considered the Crossover as variable and other parameters like the first population size, chromosome length and mutation as constant . In this paper is used pop=100;Npop=40; CL=5 bits and fix mutation ratio=0.5 for every crossover operator.Crossover operator is compared with one point,two point and uniform. Figure (5) shows the trend of objective function minimization in this step.

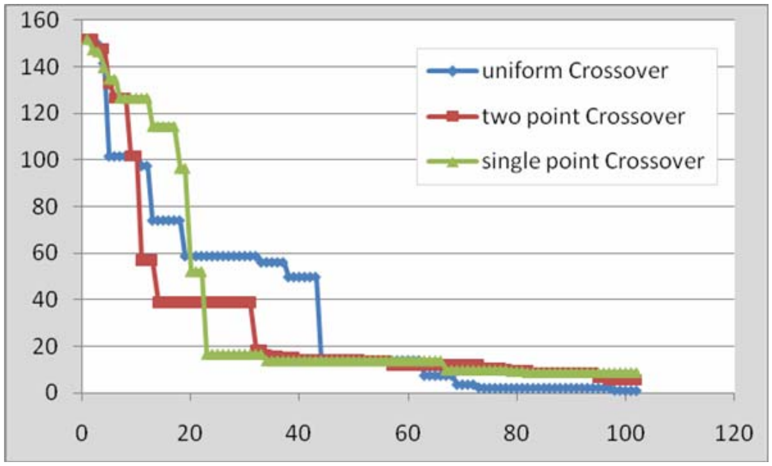

Fig. 5. Trend of minimization of the objective function in one point,two point and Uniform

As seen in figure (5), the compatibility and fast convergence of used GA method in this work for uniform crossover is clear. Uniform crossover can be considered a generalization of the other crossover methods. It was shown that in Figure (5), uniform crossover is more effective at combining schemata than either one- or two-point crossover. In addition is found that two-point crossover is consistently better than one-point crossover.

Mutation

After crossover, the strings are subjected to mutation. Mutation prevents the algorithm to be trapped in a local minimum. Mutation plays the role of recovering the lost genetic materials as well as for randomly disturbing genetic information. Mutation has traditionally considered as a simple search operator. If crossover is supposed to exploit the current solution to find better ones , mutation is viewed as a background operator to maintain genetic diversity in the population by randomly modifying some of its building blocks.

In third step is considered the Mutation as variable and other parameters like the first population size, chromosome length and Crossover as constant . In this paper is used pop=100;Npop=40; CL=5 bits and uniform crossover for different mutation ratio.mutation ratio is compared with linear and fix ratio. Figure (6) shows the trend of objective function minimization in this step.

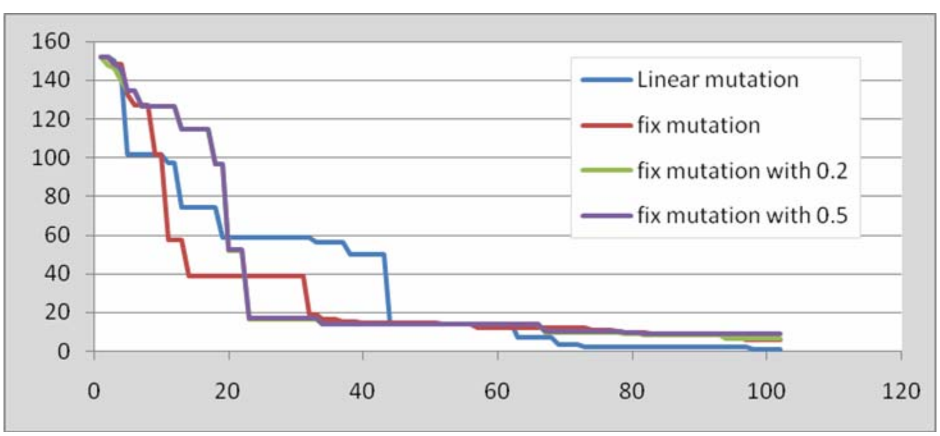

Fig. 6. Trend of minimization of the objective function in linear,constant mutation ratio

There are many different forms of mutation for different kinds of representation. Mutation operator can accelerate the search. But care should be taken , because it might also reduce the diversity in the population and makes the algorithm converge toward some local optima. So linear variable mutation ratio is used from a high value at the first generation to a low value in the last one. we tested these mutation ratio on this example in order to minimize objective function. The conclusions indicated that the variable mutation rate worked better than the constant mutation rate.Since these results were performed on one specific problem, no general conclusions about a variable mutation rate are possible.

Conclusions

A new leak detection method was introduced based on inverse transient modeling using the backward MOC and the Binary GA method. Some important aspects of leak detection are also investigated including transient modeling uncertainties and the methods of reducing their effects. It was shown that to minimize effects of uncertainties of friction loss modeling and practical problems caused by waterhammer, the downstream end valve as the transient generator should be closed gradually at a specified time duration. To omit valve effects, pressure fluctuations are measured at the valve after its full closure and the method is applied afterward. Consequently in the proposed method, there is no need to consider any valve related specification such as its type, installation, and operation (linear, nonlinear or oscillatory). Also it is not required to define the initial conditions in the numerical model. Therefore theapplication of the method found to be practical and easy to use. Using this method, at the first step, leaks' parameters are determined at characteristic nodes. Then by linear interpolation between two adjacent nodes, the leak detection can be scrutinized. The step by step application of the method shows the capability and flexibility of the method to deal with single or multiple leaks, large scale problems, and various sampling frequencies. Also it was shown that the presented method is capable of calibrating the pipe friction factor and detects leak parameters simultaneously. Furthermore, due to use of the MOC to transient analysis, the proposed leak detection method can be developed for more complicated systems including various equipments, boundary conditions and multi branches such as water supply networks. For very small leaks and high friction factors it may be difficult to detect leaks accurately by this method and likely by other existing methods. However example (4) shows that the method can deal with such problems properly.

The presented method needs to model real-life pipes numerically. For this purpose comprehensive data of the pipe specifications should be gathered which may be difficult and time consuming especially for old pipes. Although it has been concluded that moderate transients decrease effects of friction factor variations (due to unsteadiness and uncertainties), but in some cases (e.g., very small leaks), these variations could influence the results' reliability. Parameters of Genetic Algorithm are Crossover , mutation, initial population ,etc. The various crossover techniques are discussed as single point crossover, two point crossover and uniform crossover. After crossover, the strings are subjected to mutation. The various mutation techniques are discussed as fixed mutation and Linear mutation. This paper investigates kinds of parameters of Genetic Algorithm that may affect convergence and time of arriving best solution in Inverse Transients Analysis. simple genetic algorithm are carried out including mate selection and paring to reproduce a new generation, mutation and convergence testing. In all reproduced new generations chromosomes are decoded. For more information, the method of weighted random paring is considered as the policy of parent selection. Uniform crossover method is used to produce offsprings and a linear variable mutation ratio is used from a high value at the first generation to a low value in the last one. Furthermore the standard deviation of objective function values of sequence generations is considered as the GA's convergence criterion which is aimed to be less than a very small quantity of ε judged for each problem. Further investigations and experimental efforts are needed regarding the validity and practical application of the method.

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